Flavor and CP Violation Working Group Summary

Michele Papucci
(LBNL)

on behalf of the conveners: Marina Artuso, MP, Soeren Prell

Snowmass EF Workshop

April 6th, 2013

Flavor and CP Viol' in EF

- Our group focus on exploring the opportunities of studying flavor and CP viol' in high-pT collisions, in particular in production and decays of new particles that may be discovered in the run II of the LHC or at future facilities

- We also study the connection between the flavor and CP violation in these direct searches with the indirect precision studies of FCPV performed in other frontiers (mostly Intensity, such as CP and flavor viol' in B,D,K mixing and decays, lepton flavor violation, ...)

Flavor Mixing and CP viol' WG agenda in this meeting:

- Joint session with New Particles WG on Thursday morning

10:50 - 12:30 Working Group Session, 4: Flavor in New Physics Models (Flavor,NP)

Convener: Michele Papucci

Location: Auditorium

10:50 **Review on flavor constraints on New Physics models** *20'*

Speaker: Wolfgang Altmannshofer (FNAL)

Material: **Slides**

11:15 **Flavor tagging tools: flavor tagging at e+e- facilities** *10'*

Speaker: Tomohiko Tanabe (Tokyo U.)

Material: **Slides**

11:25 **Flavor tagging tools: Tau reconstruction** *10'*

Speaker: Sarah Demers (Yale U.)

Material: **Slides**

11:40 **Flavor benchmarks for the Randall-Sundrum scenario** *20'*

Speaker: Martin Bauer (U. Chicago)

Material: **Slides**

12:05 **Flavor signatures in SUSY** *20'*

Speaker: Daniel Stolarski (U. of Maryland)

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Connections with IF

- Discussion session with New Particles WG yesterday

Special thanks

- Thursday speakers: W. Altmannshofer, T. Tanabe, S. Demers, M. Bauer, D. Stolarski
- Experts who provided feedback and directions in the past months: M. Velasco, S. Gori, N. Craig, M. Blanke, D. Morrissey, G. Perez, S. Jager, K. Matchev, J. Zupan, A. Kagan, A. Weiler, D. Straub
- Feedback/suggestions/discussions in this workshop: K. Agashe, L. Wang, G. Kribs, J. Evans, J. List, B. Heinemann, ...

Work Paradigm consolidated here

IF

EF

collider studies

"Low Energy" flavor measurements (B,D,K CP and flavor viol' observables, LFV, EDMs, neutrinos)

Theoretical combination in models/scenarios

M, Γ, g

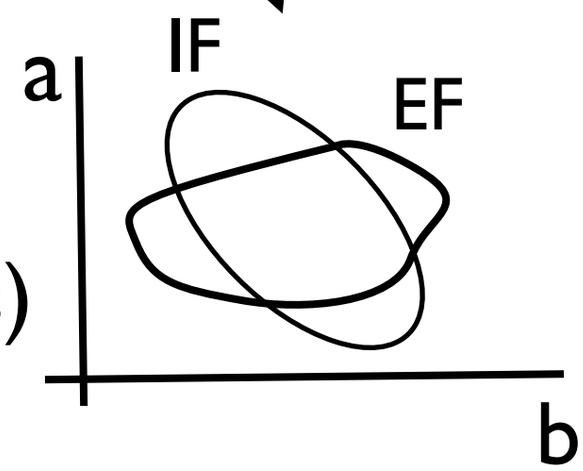
Topology A

Topology B

⋮

(Simplified models)

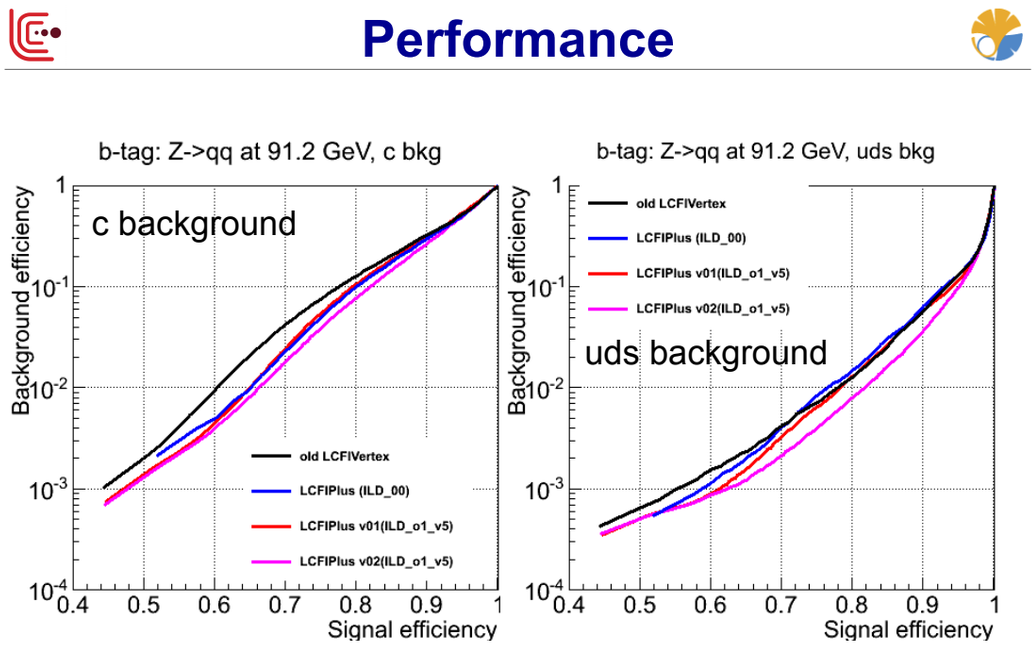
reach: (& constraints)



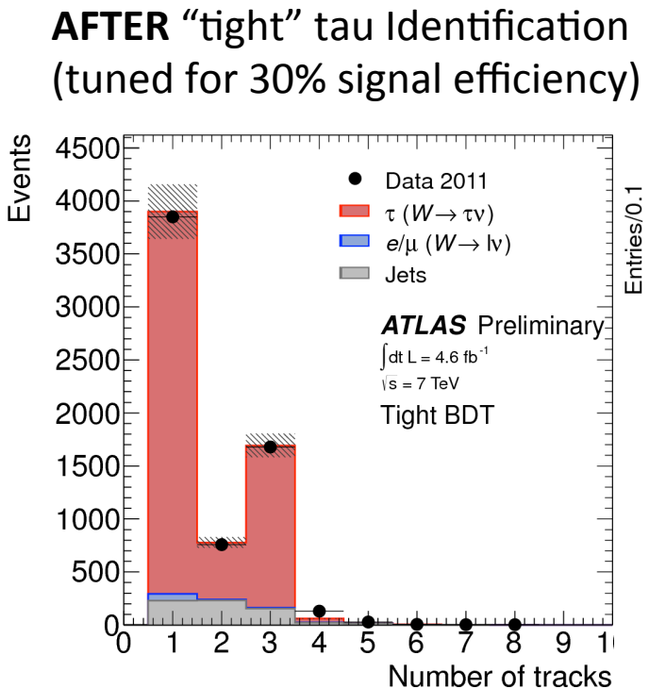
(see also talks by Bauer & Altmannshofer)

Tools

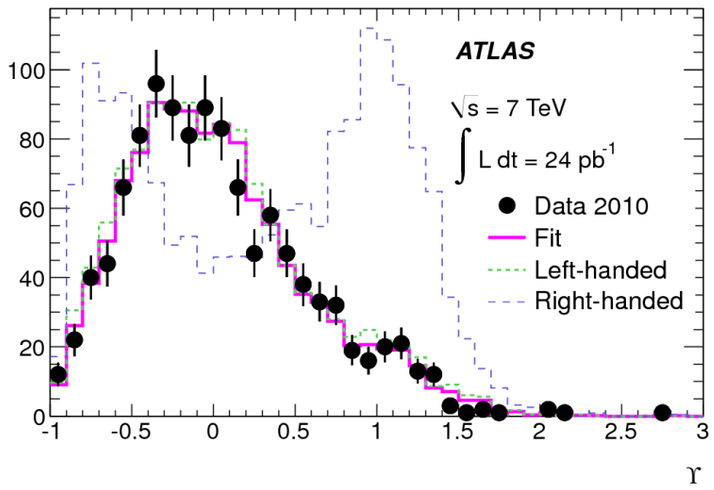
- Tagging flavor is key:
  - jet tagging:



- T reconstruction (and polarization)



S.Demers



$$P_\tau = -1.06 \pm 0.04\,(stat)\,^{+0.05}_{-0.07}\,(syst)$$

- (top reconstruction, e/μ)

Dealing with deadlines

- Studies for probing flavor generically involve:

e.g.:

$$\bar{\ell}_i \ell_i + X \to (\bar{\ell}_i \ell_i + \epsilon\, \bar{\ell}_i \ell_j) + X$$
$$\bar{q}_i q_i + X \to (\bar{q}_i q_i + \epsilon\, \bar{q}_i q_j) + X$$

Already on the agenda of the New Particles group

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- Given the time constraints we try to take advantage as much as possible on existence of past related studies and/or the possibility to "recycle" as new search channels for LHC run I

Models

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Similar story for Lepton Flavor Viol' with KK Z' → eμ, μτ, etc.

FV with (vector-like) 3rd generation partners

- $T \to t\, Z,h$ & $T \to Wb, Wt$, $B \to Wt$, $B \to b\, Z,h$ are the leading decays (already under study)

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Interesting story with constraints from B,D,K that will show up in the final comparisons

SUSY w/ R-parity

(D. Stolarski, G.Kribs, Y.Shadmi, …)

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$$\tilde{t} \to c + \mathrm{MET} \qquad \tilde{u}, c \to t + \mathrm{MET}$$

$$pp, e^+e^- \to tc + \mathrm{MET}$$ (Blanke et al. 2013)

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  - sleptons decays, e.g. (interplay with LFV searches)

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SUSY w/ R-parity

- Gaugino multibody decays (interesting signature for "Mini-Split")

MINI-SPLIT SUSY

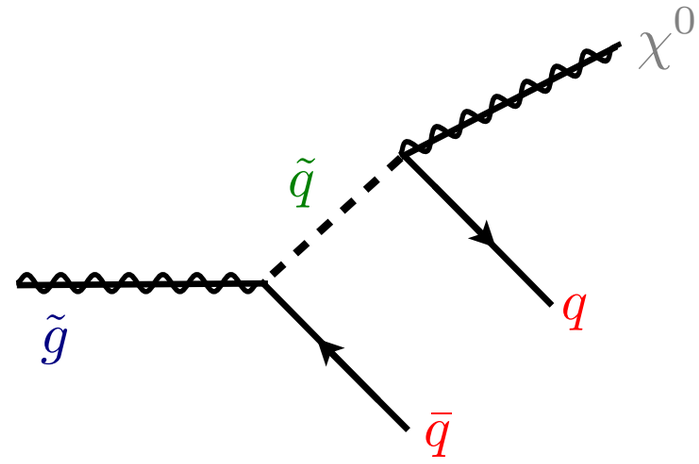
Scalars are very heavy, O(1000 TeV), gauginos can be O(1 TeV)

Arkani-Hamed, Gupta, Kaplan, Weiner, Zorawski, 2012. Arvanitaki, Craig, Dimopolous, Villadoro, 2012. Bhattacherjee, Feldstein, Ibe, Matsumoto, Yanagida, 2012

Gluino decays encode flavor information of (heavy) squarks

Two neutralino and one chargino accessible

Many flavor observables if you can flavor tag quarks



(D.Stolarski's talk)

Simplified models definitions for studies should be finalized over the next 1-2 weeks

SUSY w/ RPV

- Too many possibilities for the couplings of LLE, QLD, UDD, LH

SUSY w/ RPV

- Too many possibilities for the couplings of LLE, QLD, UDD, LH
- Restricted set studied by the NP WG:

Motivated Benchmark Models

by Naturalness, 3rd Generation Dominance and Variety of Final States

Coupling	Production	Final States	Search	Nat.	3G
*LLE*122	$\tilde{g}/\tilde{u} \to \tilde{B}$	$jj + \ell^+\ell^-\mu^+\mu^- + \not{E}_T$	Mℓ	X	X
	$\tilde{W}$	$\ell^+\ell^-\mu^+\mu^- + \not{E}_T$	Mℓ	X	X
*LLE*233	$\tilde{t} \to \tilde{H}$	$b\bar{b}\tau^+\tau^-\ell^+\ell^- + \not{E}_T$	Mℓ	✓	✓
	$\tilde{H}$	$\tau^+\tau^-\ell^+\ell^- + \not{E}_T$	Mℓ	✓	✓
*LQD*221	$\tilde{g}$	$\{\ell^\pm jj\}\{\ell^\pm jj\}$	SSℓ	X	X
*LQD*321	$\tilde{t} \to \tilde{H}$	$\{b\{\tau^+jj\}\}\{\bar{b}\{\tau^-jj\}\}$	OSτ	✓	✓
*LQD*232	$\tilde{g} \to \tilde{t}$	$t\bar{t}\{\mu^+j\}\{\mu^-j\}$	Mℓ	X	X
*LQD*333	$\tilde{t}$	$\{\tau^+b\}\{\tau^-b\}$	LQ	✓	✓
*UDD*212	$\tilde{g}$	$\{jjj\}\{jjj\}$	Trijet	X	X
	$\tilde{t} \to \tilde{B}$	$t\bar{t}\{jjj\}\{jjj\}$	ℓ + n jets	✓	X
*UDD*312	$\tilde{t}$	$\{jj\}\{jj\}$	Dijet Pairs	✓	X
*UDD*323	$\tilde{t} \to \tilde{H}$	$bb\{bbj\}\{bbj\}$	b-jets	✓	✓
*LH*3	$\tilde{H}$	$W^+W^-\tau^+\tau^-$	Mℓ	✓	✓

Nat. – A “natural” topology, i.e. stops and higgsinos

3G – RPV coupling compatible with a 3rd generation dominant ansatz

- All scans chosen to be linear in mass – others in ratio

SUSY w/ RPV

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Need to add another decay channel in a given final state

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SUSY w/ RPV

- Three representatives (w/ J.Evans):

*LLE*122	$\tilde{g}/\tilde{u} \to \tilde{B}$	$jj + \ell^+\ell^-\mu^+\mu^- + \not{E}_T$	Mℓ	*X*	*X*

+ LLE123 → look also at final state taus in the same simplified model

*UDD*312	$\tilde{t}$	$\{jj\}\{jj\}$	Dijet Pairs	√	*X*

+ UDD323 → both $\tilde{t} \to bj$ and $\tilde{t} \to jj$ (how far from MFV limit?)

*LH*3	$\tilde{H}$	$W^+W^-\tau^+\tau^-$	Mℓ	√	√

+ LH2 → $W^+W^-\mu^+\mu^-$ and interesting interplay with neutrino masses (see e.g. W. Porod)

Other cases?

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  - it is notoriously hard in hadronic machines (but not impossible) → which models/benchmarks to consider?
    - CPV in 2HDM: need to discuss/coordinate with Higgs group and with Cosmic Frontier for baryogenesis
- TeV-scale models for neutrino masses (no outstanding issues on this topic)

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- Assign "combination" studies to groups of theorists (for RS: M.Bauer & al.)
- Collect contributions on probing flavor and CP violation in high-pT collisions

- Flavor and CP Viol' Working Group page:

http://www.snowmass2013.org/tiki-index.php?page=Flavor+Mixing+and+CP+Violation+at+High+Energy

Feedback and volunteers needed!!

Backup

Charges

1- Charm, B_u and B_d, B_s and B_c and b baryons

- What new physics mass scales can be probed with flavour observables?
- How do flavor studies impact models of NP?
- What are the constraints on the model predictions imposed by beauty and charm decays?
- How we can parameterize the model predictions in terms of generic beyond Standard Model parameters affecting DeltaB=2 (DeltaC=2) and DeltaB=1 processes.

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2. Top quark

- What type of new physics models predict CP and/or Quark Flavor Violation (CPQFV) in the top sector?
- What limits can be set on NP CPQFV models with top decays?
- What measurement in top production/decay are most sensitive to NP?
- How precisely do we need to measure Vtb? Can we measure Vts or even Vtd directly?
- How well can we measure FCNC in top decays (t->c,u (gamma/Z, l+l-)?
- How well can we measure CPV in triple product correlations?
- Are there other probes of new physics (e.g. forward-backward asymmetry)?

3. Higgs

- What type of new physics models predict CP and/or Flavor Violation in the Higgs sector?
- What limits can be set on NP CP and/or FV models with Higgs decays?
- What limits can be set on LFV in Higgs decay (H->tau mu, tau e, mu e)?

4. New heavy particles

- What are the viable models of new physics at the TeV scale with Flavor non-Universality (beyond Yukawa couplings) and/or CP Violation and/or Quark and/or Lepton Flavor Violation specifically associated with new particles at the TeV scale? How can we test such models?
- What are the more interesting lifetime ranges to explore in search of “invisible particles” messengers of the hidden sector (e.g. hidden valley particles).
- What limits can be set on LFV heavy particles (X->tau mu, tau e, mu e)?

Charges

5. Leptons

- Are there tau decays in which Lepton Flavor Violation (LFV) is best seen at a dedicated experiment at a hadron collider?
- Are there models of lepton number violation at the TeV scale that can be tested at the next generation of accelerators?
- Which mass ranges and couplings can be probed for Majorana neutrinos at high energy experiments?

6. Baryons

- Are there models of baryon number violation at the TeV scale that can be tested at the next generation of accelerators?